OKLAHOMA GEOLOGY

Oklahoma Geological Survey Vol. 51, No. 5 October 1991

On the cover—

A Coiled Nautiloid from the Holdenville Formation, Collinsville, Oklahoma

The coiled nautiloid *Domatoceras* is a relatively rare taxon. It is infrequently recovered in association with other cephalopods as shell fragments and incomplete phragmacones in Pennsylvanian strata in Oklahoma. The recovery of *Domatoceras* n. sp. (lateral view; maximum diameter, 9.7 cm; maximum width, 2.9 cm; height, 4.3 cm) from Collinsville, Oklahoma, represents an exceptionally rare discovery. The Collinsville locality has been known for its fossil cephalopods since 1937 when Miller and Owen reported the occurrence of ammonoids and nautiloids from carbonate concretions in a black shale that overlies the Dawson coal (Holdenville Formation). Subsequent reports (Mapes, 1976; Mapes and Bergstein, 1987) on cephalopods from the locality dealt with the ammonoid component of the fauna. The coiled nautiloids need additional study to document their diversity.

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Oklahoma Geology Notes, ISSN 0030-1736, is published bimonthly by the Oklahoma Geological Survey. It contains short technical articles, mineral-industry and petroleum news and statistics, abstracts, notices of new publications, and announcements of general pertinence to Oklahoma geology. Single copies, $1.50; yearly subscription, $6. Send subscription orders to the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019. Short articles on aspects of Oklahoma geology are welcome from contributors; general guidelines will be sent on request.

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Oklahoma Geology Notes

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OKLAHOMA
GEOLOGICAL
SURVEY

VOL. 51, NO. 5

OCTOBER 1991

GROUND-WATER AND WASTE MANAGEMENT: TEACHING AND RESEARCH PROGRAMS AT THE UNIVERSITY OF OKLAHOMA

L. W. Canter[1]

Abstract

During the decade of the 1980s, considerable public attention and expenditures of money were directed toward the cleanup of contaminated soil and ground water. Contamination has occurred as a result of poor siting of waste-disposal facilities, less-than-adequate facility design and operation, and inadvertent and unanticipated leaks and spills. In addition, increasingly stringent control laws related to air-pollution emissions and industrial and municipal wastewater discharges have caused the generation of additional waste products and sludges that must be disposed in an environmentally responsible manner. To respond to these societal issues, graduate-level emphases in ground-water-quality management (1982) and hazardous-waste management (1990) have been developed within the School of Civil Engineering and Environmental Science (CEES) at the University of Oklahoma. These emphases are a result of increasing public attention toward waste minimization and the need for environmentally responsible disposal, which will minimize resultant soil and ground-water contamination. In addition to teaching programs, sponsored research has been conducted on the transport and fate of subsurface contaminants, and on in situ and pump-and-treat technologies for remediating contaminated soil and ground water. This article highlights these teaching and research programs that integrate ground-water and waste-management concerns.

Introduction

The decade of the 1980s saw considerable attention being directed toward the cleanup of contaminated soil and ground water in the United States. Examples of key federal laws that have caused this attention include the Comprehensive Environmental Response, Compensation and Liability Act of 1980, the Resource Conservation and Recovery Act of 1984, the Superfund Amendments and Reauthorization Act of 1986, the Safe Drinking Water Act of 1986, and the Clean Water Act of 1987. One significant aspect of this national legislation is that increased attention has been given to minimizing pollutant discharges via the inclusion of additional control measures for air-pollutant emissions, municipal- and industrial-wastewater discharges, and municipal and hazardous solid-waste disposal. As a result, there are increasing quantities of waste materials and sludges which have been subject to land disposal, with these practices expected to continue despite policy statements by the U.S. Environmental Protection Agency related to banning certain land-disposal activities.

The decade of the 1980s also saw the emergence of numerous ground-water contamination problems, which led to national attention being directed to specific cases and the expenditures necessary to remediate such contamination. Examples include Love Canal in New York, Times Beach in Missouri, and the Stringfellow Acid Pits in California.

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Oklahoma is not without locations characterized by contaminated soil and ground water, although on a relative basis the concerns are minimal when compared to more-densely populated and industrialized states along the eastern seaboard. Three examples of areas of particular concern are: (1) the Tar Creek area in northeastern Oklahoma, which was contaminated several decades ago from mining practices; (2) the Criner hazardous-waste-disposal site in south-central Oklahoma, which served as a hazardous-waste-disposal site in the 1960s and 1970s; and (3) the ground water around Cyril, which has been contaminated by petroleum operations.

In order to address emerging educational-program needs that combine ground-water and waste-management considerations, and at the same time to devote attention to the necessary research to increase society's understanding of fundamental problems and issues, CEES at the University of Oklahoma was also active during the decade of the 1980s with regard to establishing teaching and research programs that have integrated these concerns. This article focuses on some of these teaching and research programs; it begins with a brief consideration of some fundamental concepts that have provided an integrating basis for these programs.

Fundamental Concepts

Figure 1 displays the fundamental bases of the teaching and research programs in ground-water and waste management that have been developed within CEES. Specifically, the causative factors are numerous pollution sources that can lead to soil and ground-water contamination. The sources are of concern when constituents associated therewith are transported through the subsurface environment into ground-water systems. Accordingly, it is also necessary to have a basic understanding of subsurface transport and fate processes. Finally, the remediation of contaminated soil and ground water is primarily directed toward minimizing contamination that has resulted from pollution sources and the subsequent transport and fate of specific constituents.

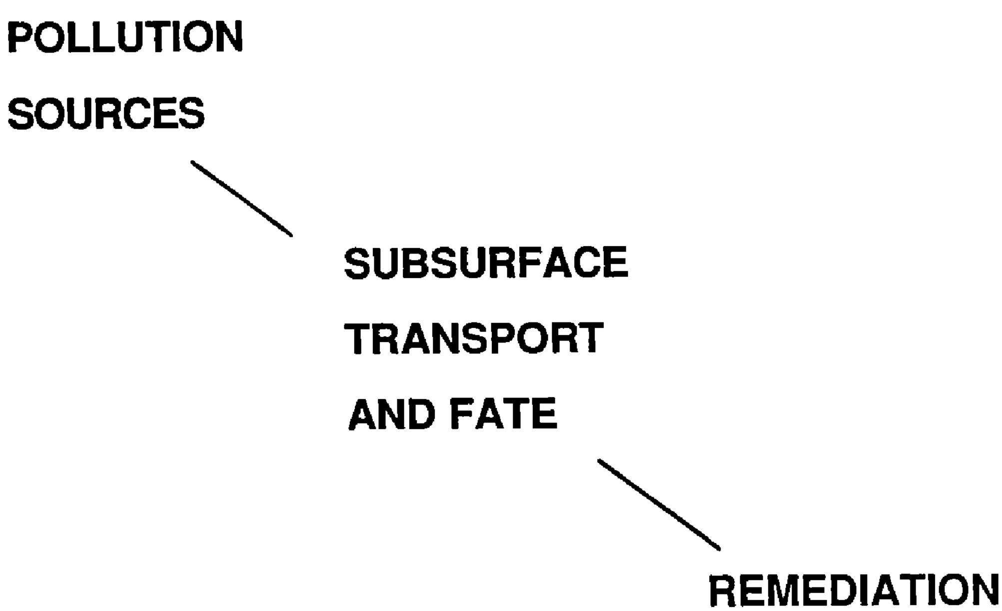

Figure 1. Fundamental bases for program.

To serve as an example of pollution sources, Table 1 delineates 33 sources organized into six categories. As can be seen from examination of this table, there are numerous potential sources that range from point sources, such as injection wells, to area-wide sources associated with ground-water contamination resulting from widespread applications of fertilizers and pesticides in agricultural areas. Additionally, Table 1 delineates man-made as well as natural sources of ground-water contamination. Within recent years, specific federal and state programs have been developed to focus special attention on certain sources; an example is the underground-storage-tank program promulgated by the U.S. Environmental Protection Agency and the 50 states.

The physical and chemical complexity of the subsurface environment makes it difficult to develop a complete understanding of all subsurface transport and fate processes. However, for purposes of convenience of consideration, such processes can be considered in terms of hydrodynamic, abiotic, and biotic processes. Hydrodynamic processes are associated with the advective (convective) movement of water through unsaturated and saturated zones in the subsurface environment. Physical phenomena associated with hydrodynamic processes include dispersion and diffusion. Abiotic processes are associated with adsorption, ion exchange, chemical precipitation, and other types of chemical reactions that can occur between contaminants and materials in the unsaturated or saturated zone. Biotic processes include the biological degradation of organic constituents during their transport though the subsurface environment.

Remediation measures for contaminated soil and ground water represent an emerging area of technology that requires the input of numerous disciplines, including engineering, geology, microbiology, and chemistry. Fundamental remediation processes can be considered in terms of source-control measures (such as the use of physical barriers), in situ biological or chemical treatment measures, or pumping and treatment measures associated with removing contaminants with the water phase and subjecting them to appropriate treatment in above-ground systems. Table 2 delineates one organizational classification for remediation technologies. It should be noted that the number of in situ and removal technologies that have potential for application to contaminated soil and ground water has been increasing in recent years.

To illustrate how these fundamental issues can be integrated, the following transport equation can be utilized for describing a one-dimensional, horizontal, single-phase flow system in a saturated, unconsolidated, homogeneous medium (Roberts and others, 1982):

$$-u\frac{\partial C}{\partial x}+D\frac{\partial^2 C}{\partial x^2}-\frac{\rho_b}{\Sigma}\frac{\partial S}{\partial t}+\left(\frac{\partial C}{\partial t}\right)_{rn}=\frac{\partial C}{\partial t} \quad (1)$$

where u = average fluid velocity (m/sec)
C = solute concentration in aqueous phase (gm/m^3)
x = distance in flow direction (m)
D = dispersion coefficient (m^2/sec)
ρ_b = bulk density of soil (gm/m^3)
Σ = soil void fraction (unitless)
S = mass of solute adsorbed per unit dry mass of soil (gm/gm)
t = time (sec)
rn = chemical reactions and/or biological degradation.

TABLE 1. — SOURCES OF GROUND-WATER CONTAMINATION
(Office Technology Assessment, 1984)

***Category I*—Sources designed to discharge substances**

Subsurface percolation (e.g., septic tanks and cesspools)
Injection wells
Land application

***Category II*—Sources designed to store, treat, and/or dispose of substances; discharge through unplanned release**

Landfills
Open dumps, including illegal dumping (waste)
Residential (or local) disposal (waste)
Surface impoundments
Waste tailings
Waste piles
Materials stockpiles (nonwaste)
Graveyards
Animal burial
Above-ground-storage tanks
Underground-storage tanks
Containers
Open burning and detonation sites
Radioactive disposal sites

***Category III*—Sources designed to retain substances during transport or transmission**

Pipelines
Materials transport and transfer operations

***Category IV*—Sources discharging substances as a consequence of other planned activities**

Irrigation practices (e.g., return flow)
Pesticide applications
Fertilizer applications
Animal feeding operations
Deicing salt applications
Urban runoff
Percolation of atmospheric pollutants
Mining and mine drainage

***Category V*—Sources providing conduit or inducing discharge through altered flow patterns**

Production wells
Other wells (nonwaste)
Construction excavation

***Category VI*—Naturally occurring sources whose discharge is created and/or exacerbated by human activity**

Ground-water/surface-water interactions
Natural leaching
Salt-water intrusion/brackish-water upconing (or intrusion of other poor-quality natural water)

TABLE 2. — PREVENTION AND REMEDIAL MEASURES
(Canter and others, 1987)

Group/Technologies	Description
Source Control Strategies I. Volume reduction measures A. Recycling B. Resource recovery C. Centrifugation D. Filtration E. Sand drying beds II. Physical/chemical alteration measures A. Chemical fixation B. Detoxification C. Degradation D. Encapsulation E. Waste segregation F. Co-disposal G. Leachate recirculation	Source control strategies represent attempts to minimize or prevent ground-water pollution before a potential polluting activity is initiated. The objectives of source-control strategies are to reduce the volume of waste to be handled, or reduce the threat that a certain waste possesses by altering its physical or chemical makeup.
Well Systems I. Well point systems II. Deep well systems III. Pressure ridge systems IV. Combined systems V. Immiscible (hydrocarbon) contaminant recovery systems	Well systems for ground water pollution control are based on manipulation of the subsurface hydraulic gradient through injection and/or withdrawal of water. Well systems are designed to control the movement of the water phase directly and the subsurface contaminants indirectly. This approach is referred to as plume management. Well systems are also used for recovery of immiscible contaminants, usually hydrocarbons, that float on the water table.
Interceptor Systems I. Collector drains A. Leachate collection systems B. Interceptor drains C. Relief drains II. Interceptor trenches A. Actively pumped systems B. Gravity flow, skimmer pump systems	Interceptor systems involve excavation of a trench below the water table, and possibly the placement of a pipe in the trench. The trench can be left open (interceptor trench), or backfill can be placed on a pipe in the trench (collector drain). Interceptor trenches can be either active (pumped) or passive (gravity flow). These systems function similarly to an infinite line of extraction wells by effecting a continuous zone of depression running the length of the trench.
Surface Water Control, Capping, and Liners I. Natural attenuation (no liner, no cap) II. Engineered liner III. Engineered cover IV. Engineered cover and liner	These three technologies are used in conjunction with each other, each serving a unique ground-water-pollution prevention purpose. Surface-water-control measures reduce potential infiltration by minimizing the amount of surface water flowing onto a site. Capping is designed to minimize the infiltration of any surface water or direct precipitation that does come onto a site. Impermeable liners provide ground-water protection by inhibiting downward flow of low-quality leachate and/or attenuating pollutants by adsorption processes.

TABLE 2. — *Continued*

Group/Technologies	Description
Impermeable Barriers I. Steel sheet-piles II. Grout curtains or cutoffs III. Slurry walls	Barriers are measures designed to influence the subsurface hydraulic gradient by placing a low permeability material into the subsurface. Barriers typically are constructed with driven sheet piles, injected grouts, or dug slurry walls. Sheet-piles provide immediate impermeability, while grouts and slurries both are emulsions that require a hardening period to achieve impermeability.
In-situ Treatment I. In-situ chemical II. In-situ biological	The in-situ treatment methods involve adding materials to the subsurface so as to cause or increase the rate of a reaction that will render a contaminant immobile or remove the contaminant. The in-situ chemical technologies attempt to immobilize contaminants through some chemical reaction, while the in-situ biological techniques are designed to provide an environment suitable for microorganisms to utilize the contaminant as a food source.
Innovative Technologies I. Block displacement II. Envirowall III. Fly ash stabilization	Three of the innovative technologies that have yet to find wide applicability are the block displacement method, the Envirowall concept, and fly ash stabilization. The block displacement method is similar to grouting except the emulsion is injected laterally with the effect of raising or isolating a whole block of contaminated soil. The Envirowall concept involves vertical placement of a synthetic liner material within a slurry wall. Fly ash stabilization involves injection of fly ash into an existing impoundment to solidify the contained liquid or slurry.
Wastewater Treatment I. Air steam stripping II. Carbon adsorption III. Biological treatment IV. Chemical precipitation	Wastewater treatment technologies are utilized at the surface to treat contaminated ground water. The technologies most widely applied to organic contaminants are air stripping, carbon adsorption, and biological treatment. Chemical precipitation is used for inorganics and metals removal.

The first term in equation 1 relates to advection or convection, and the second term addresses dispersion. Adsorption is incorporated in the third term, and other abiotic reactions and biological degradation are accounted for in the fourth term.

The important point to note from this equation is that it is possible to describe the subsurface environment via quantitative modeling; however, there are numerous limitations of such models at the current time. Modeling and its limitations are also considered to be an important facet of the teaching and research programs at the University of Oklahoma.

To serve as an example of how equation 1 can be used in ground-water and waste-management decision-making, the following potential mitigation measures could be analyzed via changes in the appropriate terms:

1) Decrease ground-water usage for projects involving use of the ground-water resource.

2) Develop comparative information to enable more-systematic site selections, which will make maximum use of the natural attenuation capacity of given environmental settings relative to preventing ground-water contamination.

3) For projects which may be of concern due to leachate generation, take measures to immobilize the constituents and prevent their occurrence in leachate via the use of waste-solidification techniques.

4) For projects wherein waste-disposal sites are relevant, consider converting the waste materials to products of lesser environmental concern; in addition, for such waste sites consider usage of engineered controls, such as site covers, liners, and leachate-collection and treatment systems.

5) If the project involves the use of agricultural chemicals, consider measures that could be used to better plan the timing of chemical applications, the rate of application, and the extent of such applications; in addition, nitrification inhibitors could be used to minimize nitrate contamination of ground water.

Teaching Programs

The School of Civil Engineering and Environmental Science has a long history involving waste-management concerns, with the early history primarily focused on municipal and industrial waste-water treatment. In the 1950s and 1960s the program was called the School (or Department) of Civil Engineering and Sanitary Science and Public Health. In the mid-1960s the name was changed to the School of Civil Engineering and Environmental Science (CEES). The program in the 1960s and 1970s was heavily focused upon traditional topics and issues addressed by sanitary (or environmental) engineers or sanitarians. Graduate-level coursework and research was primarily based on a public-health perspective, with attention given to appropriate treatment technologies and evaluation of environmental stresses. One example of a specific waste-management effort was a U.S. Environmental Protection Agency solid-waste-management training grant, which was administered in CEES from 1970 to 1974.

As noted earlier, the decade of the 1980s can be characterized by an increased emphasis on the subsurface environment and ground water as a medium upon which environmental-management requirements were being increasingly placed. This is in contrast to traditional environmental programs that focused upon air quality and surface-water quality and quantity concerns.

In 1980, a survey was made of approximately 300 universities in the United States and Canada to inquire as to their ground-water-related course offerings. Responses were received from about 80 universities, and the general finding was that ground-water-related courses were typically found in either geology or civil engineering departments. Furthermore, it was determined that the courses tended to be focused upon quantitative features of the resource, as exemplified by numerous courses on ground-water hydrology.

In 1982, a ground-water-quality management emphasis was introduced within the graduate programs in CEES. There are two basic master's degree options: namely, a Master of Science in Civil Engineering, or a Master of Environmental Science. The emphasis was planned so as to enable the participation of students with academic backgrounds in engineering, geology, microbiology, and chemistry. Five specific courses were delineated as the core courses in this master's-level emphasis, with these courses identified in Table 3. As the program has developed, additional courses have been added so as to provide greater attention to waste management. One example of this is a course entitled Hazardous Waste Manage-

Table 3. — Graduate-Level Courses Related to Ground-Water and Waste Management

Course No.[a]	Title	Ground water	Waste Management (hazardous and solid waste)	Waste Management (process design)
CE 4123	Open Channel Flow	E[b]		E
CE 5020	Multi-Use Environmental Management	E	E	
CE 5123	Stream Channel Mechanics and River Engineering	E		E
CE 5244	Water and Waste Treatment	E	T[c]	C[d]
CE 5263	Hazardous Waste Management and Toxicology	T	C	E
CE 5363	Hazardous and Solid Waste Design	E	C	T
CE 5600	Environmental Quality Management Field Training	E	E	E
CE 5803	Solid Wastes Systems Planning	E	C	E
CE 5833	Ground Water Quality Protection	C	E	E
CE 5843	Hydrology	E		E
CE 5853	Ground Water and Seepage	C	T	E
CE 5863	Environmental Impact Assessment	E	E	E
CE 5873	Water Quality Management	E		E
CE 5883	Numerical Modeling of Subsurface Water Systems	C		E
CE 5893	Ground Water Pollution Control	C	T	E
CE 5923	Air Pollution Control Engineering		C	T
CE 6624	Biological and Industrial Wastewater Treatment and Reuse	E	T	C
ES 5013	Environmental Epidemiology and Statistical Interpretation		T	
ES 5113	Chemical Aspects of Environmental Science	C	C	C
ES 5133	Advanced Environmental Biology		E	E
ES 5223	Advanced Environmental Chemistry		E	E
ES 5273	Safety Engineering and Management		E	
ES 5323	Biological Aspects of Environmental Science	E	E	C
ES 5473	Soil Science	T	E	
ES 5603	Environmental Science	E	E	
ES 5653	Industrial Hygiene		E	
ES*RA	Risk Assessment	E	T	

* New course.

[a] CE, Civil Engineering; ES, Environmental Science.

[b] E denotes an elective.

[c] T denotes selected technical area course; for ground-water emphasis, need to choose either CE 5263 or ES 5473 (the other course could be taken as an elective); for hazardous- and solid-waste emphasis, must choose CE 5853 and CE 5893 or CE 5244 and CE 6624 or ES 5013 and ES RA (the other courses could be taken as electives); for process-design emphasis, must choose CE 5923 or CE 5363 (the other course could be taken as an elective).

[d] C denotes core (or required) course.

ment and Toxicology (CE 5263), which has been taught for approximately five years.

In the fall of 1990, a new emphasis was added to the graduate programs in CEES; this emphasis focuses upon hazardous- and solid-waste management. This new emphasis is complementary to the ground-water-quality management emphasis. Again, the two basic master's degrees are a Master of Science in Civil Engineering or a Master of Environmental Science. The specific core-course requirements for the hazardous- and solid-waste management curriculum are also delineated in Table 3.

As these CEES educational programs have developed, several faculty members in the School of Geology and Geophysics have delineated their interests in hydrogeology; accordingly, the School of Geology is developing a complementary graduate emphasis which will lead to a master of science degree with the focus on hydrogeology. There is coordination and usage of coursework from both CEES and the School of Geology in these complementary academic programs.

It should be noted that while the emphasis herein has been on master's programs, CEES does offer a Ph.D. degree for individuals who wish to emphasize either ground-water-quality management or hazardous- and solid-waste management. In addition, a third program emphasis in CEES that should be noted in this context is the program focused on pollution-control process design. This emphasis is primarily directed toward coursework and research on technologies for controlling air-pollutant, water-pollutant, and solid- and hazardous-waste emissions.

One teaching opportunity that has been extremely successful within CEES was implemented in 1971 on the Statewide talkback television system. Coursework is offered live via a microwave transmission system to more than 15 receiving locations distributed throughout Oklahoma. In addition to the television offerings, in any given semester there are typically four to eight graduate-level courses offered in the evening. These offerings facilitate opportunities for graduate-level training for professionals working full time in the Oklahoma City area, or, for that matter, via the talkback television system, anywhere in Oklahoma.

Faculty

The decade of the 1980s also saw an increase in the number of faculty within the Environmental Engineering and Environmental Science areas in CEES. The full-time faculty currently includes four environmental engineers, three hydrologists, one chemist, one microbiologist, and one industrial hygienist. As a result of academic cross appointments, the faculty also includes two persons who have environmental-policy interests and one person who specializes in radiation safety. Therefore, 13 faculty members within CEES have either direct or related interests in ground-water and waste management.

Research Programs

As teaching programs have developed, corresponding development has also occurred in research programs related to ground-water and waste management. While the School has traditionally been a major program at the University in terms of sponsored research, and while considerable environmentally related research has been conducted for three decades, the emphasis herein will be on targeted activities that occurred primarily over the last decade.

An initiating event in establishing a research program was the awarding of the National Center for Ground Water Research (NCGWR) in 1979 by the U.S. Environmental Protection Agency. The NCGWR is comprised of three universities in a consortium relationship—the University of Oklahoma, Oklahoma State University, and Rice University. The focus of the NCGWR research has been primarily directed toward subsurface transport and fate processes, and in the development of a more fundamental understanding of the factors that influence such processes.

In 1982, the Environmental and Ground Water Institute (EGWI) was formed as the first organized research unit within the College of Engineering. The objectives of EGWI are as follows:

1) To conduct basic and applied research on techniques for predicting impacts on the physical-chemical, biological, and socio-economic environment, and on methodologies for environmental-impact assessment and comparison of alternatives.

2) To conduct basic and applied research on ground-water-pollution control, pollutant transport and fate, ground-water-quality management, and ground-water reclamation.

3) To develop and provide educational opportunities to individuals interested in emphasizing environmental impact assessment and/or ground-water-quality management in graduate degree and/or continuing education programs.

Since 1982, the annual level of external funding that has been procured for research associated with ground-water and waste management has varied from about $0.35 million up to approximately $0.75 million. Numerous projects have been conducted for federal agencies such as the U.S. Environmental Protection Agency, the U.S. Soil Conservation Service, the U.S. Army, and the U.S. Navy. Research has also been conducted under sponsorship of State agencies such as the Oklahoma Corporation Commission. Also, private research support has been provided via an entity called the Ground Water Corporate Forum.

While it is difficult to neatly categorize all the research activities that have been conducted in CEES in the 1980s related to ground-water and waste management, three fundamental research areas can be identified. Research has been conducted on pollution-source prioritization, remediation technologies, and subsurface biotic and abiotic processes. Table 4 includes a representative list of recent project titles. Research related to pollution-source prioritization has focused on selected source categories such as septic-tank systems and the potential for soil and ground-water contamination resulting from the drilling and use of oil and gas wells.

Research in the context of remediation technologies has been exemplified by both state-of-the-art literature surveys as well as laboratory studies to develop appropriate technologies for meeting specific needs. Examples of these laboratory studies include work related to the biodegradation of trichloroethylene in fixed-film bioreactors using methane as a primary substrate, the potential for using photochemical oxidation for treatment of ground water contaminated with organics, and the potential for use of vacuum-extraction systems for removing volatile organics from the subsurface environment.

Research related to biotic and abiotic processes has been primarily associated with laboratory studies of the factors related to biodegradation of contaminants in

TABLE 4. — EXAMPLES OF TITLES OF RECENTLY COMPLETED OR ONGOING GROUND-WATER AND WASTE-MANAGEMENT RESEARCH PROJECTS

Innovative Ground Water Treatment Technologies
Field Demonstrations of Remediation Technologies for Underground Fuel Tank Spill Cleanup Programs
Remediation of PCBs in Contaminated Soils via Biodegradation or Surfactant Flushing
Ground Water Remediation Technology Assessment—Biological and PAC Treatment Technology
Ground Water Remediation Technology Assessment—Photochemical Oxidation Treatment Technology
Adsorbing Tracers for Ground Water Contaminant Transport
Modeling of Nonequilibrium Adsorption
Use of Rotating Biological Contactors for Treatment of Aircraft Paint Stripping Wastewaters; and Ground Water Contamination Potential of Treatment Sludges
Nitrification–Denitrification of Sodium Nitrite Wastewater
Nonpoint Source Pollution Prioritization and Modeling
Development of Non-Fickian Solute Transport Model Based on Experimental Investigation of Dispersion and Flow Velocity in Porous Media
Development of a Nitrate–Nitrite Analysis Technique and Heavy Metals Removal Method for Boiler Tube Wastewater
Advanced Subsurface Characterization for Sorptive Processes Using Nonionic Surfactants

the subsurface environment, and the removal of contaminants via adsorption, ion exchange, or chemical precipitation.

The research conducted can be characterized as ranging from literature-based research, to planning and conducting laboratory and field studies, to developing and using mathematical models that simulate transport and fate processes in the subsurface environment.

Conclusions

This article has summarized the activities related to ground-water and waste management conducted during the 1980s within the School of Civil Engineering and Environmental Science at the University of Oklahoma. Several technical and policy conclusions that can be drawn relative to the experience developed and emerging needs are:

1) The overall field of ground-water and waste management is evolving, in that information is becoming available that enables a more scientific approach to be taken for management purposes. Policy changes and regulatory requirements continue to be developed which lead to greater emphasis on certain subjects at particular points in time. One example of this is the current emphasis on the underground-

storage-tank program. It is expected that the evolving nature of these topical areas will continue through the decade of the 1990s.

2) In order to have a responsible teaching and research program, an interdisciplinary approach is needed when dealing with soil and ground-water contamination. This interdisciplinary approach is reflected in the faculty expertise within CEES and the degree options that enable individuals with backgrounds from engineering, geology, chemistry, or microbiology to participate.

3) In addition to an interdisciplinary approach, it is also necessary for professionals working in these fields to have an appreciation for the concerns and input of other disciplines. For example, the person with an engineering background must develop an additional understanding of hydrogeology, chemistry, and microbiology; and the geologist needs to develop additional appreciation for the role of engineers and specific concerns and inputs of chemists and microbiologists.

4) There continue to be many needs for teaching and research in ground-water and waste management. One of the needs is to further integrate technology and policy concerns. This particular need can be met through the integration of policy-related courses in the program.

In summary, perhaps the greatest focus of attention in the decade of the 1990s should be on prevention of further contamination of soil and ground water. Preventative measures must be developed, while at the same time there is continuing work on remediation measures to clean up mistakes from the past.

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Water Type and Concentration of Dissolved Solids, Chloride, and Sulfate in Water from the Ozark Aquifer in Missouri, Arkansas, Kansas, and Oklahoma

The Ozark aquifer, the thickest and most permeable geohydrologic unit in the Ozark Plateaus Province, is widely used as a source of domestic and municipal drinking water and for industrial and agricultural use. J. L. Imes and J. V. Davis prepared the maps at a scale of 1:750,000 (1 in. = ~12 mi), showing water type and concentration of dissolved solids, chloride, and sulfate in ground water from the aquifer. Latitude 35° to 39°, longitude 89° to 96°. Each color sheet measures 40 × 35 in. The concentration of dissolved solids, chloride, and sulfate in the ground water generally is within recommended limits of the U.S. Environmental Protection Agency for potable water, except on the flanks of the Ozark uplift where the mainly freshwater system contacts surrounding aquifer systems containing saline water.

Order HA 0711-K from: U.S. Geological Survey, Map Distribution, Federal Center, Box 25286, Denver, CO 80225. The price is $9.60. (A $1 postage and handling charge is applicable on orders of less than $10.)

Surface Water of Kiamichi River Basin in Southeastern Oklahoma

Prepared in cooperation with the Oklahoma Water Resources Board, this 39-page USGS open-file report by L. L. Laine contains a section on quality of water by T. R. Cummings.

Order OF 63-0152 from: U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $4 for microfiche; add 25% to the price for foreign shipment.

Geophysical Logs for Selected Wells in the Picher Field, Northeast Oklahoma and Southeast Kansas

The Roubidoux aquifer in northeastern Oklahoma is used extensively as a source of water for public supplies, commerce, industry, and rural water districts. The Roubidoux aquifer may be subject to contamination from abandoned lead and zinc mines of the Picher field. In 1984, the Oklahoma Water Resources Board began to locate abandoned wells that might be serving as conduits for the migration of contaminants from the abandoned mines. A total of 66 wells were located, cleared of debris, and plugged by July 1985. In cooperation with the OWRB, the USGS obtained geophysical logs, which are presented by S. C. Christenson, T. B. Thomas, M. D. Overton, R. L. Goemaat, and J. S. Havens in this 93-page open-file report. The geophysical logs include hole diameter, normal, single-point resistance, fluid resistivity, natural-gamma, gamma-gamma, and neutron logs. Depths logged range from 145 to 1,344 ft.

Order OF 91-213 from: U.S. Geological Survey, Water Resources Division, 202

N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 231-4256. A limited number of copies are available free of charge.

Analytical Data for Bituminous Coals and Associated Rocks from Arkansas, Iowa, Kansas, Missouri, Nebraska, and Oklahoma

Written by S. J. Tewalt and R. B. Finkelman, this USGS open-file report contains 50 pages.

Order OF 90-0669 from: U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $4 for microfiche and $7.75 for a paper copy; add 25% to the price for foreign shipment.

UPCOMING MEETINGS

Fifth International Ground-Water Modeling Conference, February 11–13, 1992, Dallas, Texas. Information: Education Dept., National Water Well Association, 6375 Riverside Dr., Dublin, OH 43017; (614) 761-1711.

Geological Society of America, South-Central Section, Annual Meeting, February 24–25, 1992, Houston, Texas. Information: Hans G. Avé Lallemant, Dept. of Geology and Geophysics, Rice University, P.O. Box 1892, Houston, TX 77251; (713) 527-4889.

Formation Damage Control Meeting, February 26–27, 1992, Lafayette, Louisiana. Information: Society of Petroleum Engineers, Box 833836, Richardson, TX 75083; (214) 669-3377, fax 214-669-0135.

Permian Basin Oil and Gas Recovery Meeting, March 15–18, 1992, Midland, Texas. Information: Society of Petroleum Engineers, Box 833836, Richardson, TX 75083; (214) 669-3377, fax 214-669-0135.

Oklahoma Geological Survey and U.S. Department of Energy, Workshop on Structural Styles in the Southern Midcontinent, March 31–April 1, 1992, Norman, Oklahoma. Information: Kenneth S. Johnson, OGS, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031, fax 405-325-3180.

Society of Petroleum Engineers, Gas Meeting, April 13–14, 1992, Midland, Texas. Information: SPE, Box 833836, Richardson, TX 75083; (214) 669-3377, fax 214-669-0135.

Society of Petroleum Engineers and U.S. Department of Energy, Enhanced Oil Recovery Meeting, April 22–24, 1992, Tulsa, Oklahoma. Information: SPE, Box 833836, Richardson, TX 75083; (214) 669-3377, fax 214-669-0135.

Geological Association of Canada/Mineralogical Association of Canada, Joint Annual Meeting, May 25–27, 1992, Wolfville, Nova Scotia, Canada. Information: Aubrey Fricker, General Secretary, Atlantic Geoscience Centre, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, N.S. B2Y 4A2, Canada; (902) 426-6759, fax 902-426-4465.

OKLAHOMA ABSTRACTS

The Oklahoma Geological Survey thanks the American Association of Petroleum Geologists, the Geological Society of America, the Society for Sedimentary Geology, and the authors for permission to reprint the following abstracts of interest to Oklahoma geologists.

Bedded Cherts in the Early Ordovician Arbuckle Group of Southwestern Oklahoma

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Bedded cherts are a rarely occurring but environmentally significant facies in the Early Ordovocian Arbuckle Group. Two such units have been identified: one in the Cook Creek Formation and one in the Kindblade Formation. In each, microcrystalline calcite and dolomite alternate in thin laminae with microcrystalline silica in units up to 25 cm in thickness. The areal extent of the bedded cherts encompasses more than 130 km^2.

It is hypothesized that the interlaminated cherts and micrites were deposited in very shallow marine conditions. A relatively small part of the Oklahoma Aulacogen was cut off from open ocean circulation, resulting in an isolated lagoon. The chert/micrite couplets may represent seasonal deposits in the lagoon. During seasonal flooding, slightly deeper water resulted in algal growth with accompanying precipitation of carbonates and solution of detrital quartz sand. During the dry season, the dissolved silica precipitated, resulting in thin layers of microcrystalline chart. Some carbonate layers contain small pseudomorphs after what may have been gypsum and anhydrite crystals and nodules, indicating that salinities increased enough to permit formation of evaporites. At least ten couplets occur in the thickest units, suggesting that the lagoon existed for ten wet-dry seasons.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 75, p. 657–658, March 1991.

The Vanoss Conglomerate—Upper Pennsylvanian Detritus Shed from the Arbuckle Uplift

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The Vanoss Conglomerate is an uppermost Pennsylvanian clastic deposit that mantles the northern slopes of the Arbuckle uplift in Murray County, southern Oklahoma. The Vanoss is comparable in genesis and position to other Pennsylvanian deposits that were shed from the Ancestral Rockies/Southern Oklahoma uplift

systems (e.g., the Post Oak, Collings Ranch, Granite Wash, and Fountain Formations). The deposit consists of a few hundred metres of (in order of descending abundance) coarse crudely bedded conglomerates, sandstones of various grain sizes, siltstones and mudstones, nodular carbonates and thinly bedded micritic limestones. We interpret the Vanoss as a record of deposition in the following environments: (i) alluvial fan—individual fans were small and subject to flashy discharge; (ii) flood plain—paleocurrent data and grain size studies suggest that the conglomerates debouched onto a flood plain that extended northwards towards modern day Kansas; (iii) lacustrine—rare limestones and associated fine clastics were laid down in small shallow lakes that occupies depressions adjacent to fans; (iv) paleosols—the nodular limestones in the section are interpreted as calcretes (an interpretation supported by textural and isotope data).

Provenance of the clastics can be clearly related to the underlying tectonically deformed Lower Paleozoic section that forms the Arbuckle uplift; in detail it is possible to partition the fans on the basis of variations in clast composition.

Although the Vanoss displays very gentle dips and evidently post dates the major tectonism that uplifted the Arbuckle area, the Formation does display features that suggest some tectonism accompanied deposition, e.g., clastic dikes and slumped horizons. In addition, we have noted a fault that shows clear evidence of movement prior to consolidation of the strata.

Most diagenetic imprint on the section took place early in the history of the deposit and involved the precipitation of (in decreasing amount) calcite, quartz, hematite and dolomite cements (both the quartz and dolomite are syntaxial). In addition, oil migrated through the Vanoss in many areas. Initial migration was contemporaneous with deposition of the conglomerate in some places.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1991*, v. 23, no. 4, p. 9.

Pennsylvanian Deformation in the Eastern Slick Hills, Southwestern Oklahoma

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The Slick Hills of southwestern Oklahoma are the exposed portion of the Frontal Fault Zone (FFZ), an area of intense Pennsylvanian/early Permian deformation that lies between the Anadarko basin and the Wichita uplift. The zone trends approximately N60W, following the line of the Southern Oklahoma aulacogen, which itself appears to have been controlled by a line of basement weakness that existed c. 1.3 bya. Maximum stratigraphic downthrow (to the northeast) across the FFZ is c. 13,000 m.

In the area of the Slick Hills, the southern boundary of the FFZ is formed by the Meers fault, a steep reverse fault that has a stratigraphic throw of c. 4,000 m. The Slick Hills are divided into two distinct blocks—Eastern and Western—by the Blue Creek Canyon fault, an oblique slip (left lateral, high angle reverse) fault that has a stratigraphic downthrow of approximately 800 m to the southwest. The northern boundary of the FFZ is formed by the Mountain View fault, a 40° dipping reverse fault that has a stratigraphic throw of up to 8,000 m to the northeast. To the east of the Slick Hills much of the throw on the Mountain View fault is transferred to the Meers system by a series of N30W thrust faults, herein collectively referred to as the Broxton fault zone.

Previous work has established that the intense deformation in the Western Slick Hills is the product of a stress system that was oblique (in a left lateral transpressive sense) to the N60W trend of the major faults in the FFZ. Our analysis of the Eastern Slick Hills has involved both field and subsurface data. The style of deformation in the Eastern Hills is less intense than the seen in the Western Hills. The principal structure is a northeastward dipping, basement-involved reverse fault, the Stony Point fault. The sense of throw on this fault is similar to that of the Blue Creek Canyon fault (i.e., it can be loosely defined as a back thrust in relation to the FFZ as a whole). Our analysis of fracture patterns and vein arrays suggests that the principal compressive stress that affected the area was oriented c. N45–60W. This is geometrically consistent with a displacement vector of N77W that has been obtained form data (fold orientations, pressure solution orientation in shear belts and fracture patterns) in the Western Slick Hills. A stress orientation with this vector would induce dominantly dip slip motion on the faults of the Broxton fault zone; this prediction is compatible with our subsurface interpretation of them as a series of low angle reverse faults. The same vector would have produced left lateral oblique compression across structures that parallel the N60W trend of the aulacogen.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1991*, v. 23, no. 4, p. 97–98.

Origin of Magnetization in the Lower Arbuckle Group, Southern Oklahoma

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Paleomagnetic results from Lower Arbuckle Group (late Cambrian–early Ordovician) carbonates in southern Oklahoma suggest the presence of at least two components. Both components reside in magnetite based on maximum unblocking temperatures below 580°C and the results of rock magnetic experiments. Specimen directions have a streaked distribution between a SSE and shallow direction and an ESE and shallow direction. The SSE endmember was probably acquired in the late Paleozoic during the Reversed Superchron. The ESE endmember is interpreted to be an early Paleozoic magnetization. Although a few samples have curved demagnetization trajectories on Zijderveld diagrams, the magnetization in most specimens decays in a linear fashion. This is interpreted to result from an almost complete overlap of blocking temperatures. Variations of magnetic intensity along the streaked path support the interpretation that there is vector addition of two components. The early Paleozoic magnetization is interpreted as being either a detrital remnant magnetization or a chemical remnant magnetization. The late Paleozoic magnetization is probably a CRM related to migration of fluids (hydrocarbons, basinal?) contemporaneous with regional deformation.

A previous paleomagnetic study of the Lower Arbuckle Group established the presence of an early Paleozoic magnetization residing in magnetite and a non-pervasive late Paleozoic magnetization in hematite associated with weathering zones. Our study supports the occurrence of an early Paleozoic magnetization, but indicates that differing local conditions can give rise to different late Paleozoic magnetizations.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1991*, v. 23, no. 4, p. 100.

Paleokarstic Phenomena of the Lower Ordovician Red Bed Sequences of the Arbuckle Group, Southern Oklahoma

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Oil and gas production has been reported recently from paleokarstic Arbuckle reservoirs in the Ardmore and Arkoma basin. The West Spring Creek and the Kindblade formations apparently exhibit karstic features.

The most extensive surface exposure of these formations is on the southern flank of the Arbuckle anticline along Interstate 35 north of Ardmore, Oklahoma. The lithology is predominantly limestone, ranging from argillaceous mudstone to oolitic and/or bioclastic grainstones. However, minor amounts of sandstone were also observed. These lithologies are characteristic of various peritidal facies.

Of particular interest in this outcrop are three distinct red bed zones. Although the zones are part of the repetitive shallowing-upward cycles that characterize the West Spring Creek Formation, ample evidence suggests the red beds represent subaerial exposure surfaces where karstification took place. Many of the thin bedded, rubbly mudstones and wackestones actually represent varieties of breccia commonly associated with karst. Collapse and crackle breccia are most commonly observed. Small solution channels and other vugs are usually completely occluded by calcite cement. However, solution cavities or vugs with diameters larger than 10 cm (3.9 in.) are lined with drusy calcite. Hematite-impregnated sediment occurs as thinly laminated infilling of solution vugs and cavities and also acts as a cementing agent of collapse breccias. Preliminary evidence suggests that karstification processes were active during Arbuckle deposition.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 75, p. 1117, June 1991.

Early Ordovician Cool Creek Dolomite, Middle Arbuckle Group, Slick Hills, SW Oklahoma, U.S.A.: Origin and Modification

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Dolomite in the Early Ordovician Cool Creek Formation of the Arbuckle Group, Slick Hills, SW Oklahoma, occurs as massive bodies in sabkha-like sequences. Petrographically, the dolomite displays euhedral to anhedral (and xenotopic), fine-to coarse-crystalline textures. Chemically, it is characterized by nearly stoichiometric composition ($Ca_{1.01}$ $Mg_{0.99}$ $[CO_3]_2$) and low $\delta^{18}O$ values (–7.6 to –9.9‰, PDB), and has a large range of $^{87}Sr/^{86}Sr$ ratios (0.70843 to 0.70894) relative to associated limestone (0.70879 to 0.70897) and coeval Early Ordovician seawater. The $^{87}Sr/^{86}Sr$ ratios of most (65%) dolomite samples fall in the $^{87}Sr/^{86}Sr$ range of coeval seawater.

The distribution of Cool Creek dolomite in sabkha-like sequences, coupled with dominant $^{87}Sr/^{86}Sr$ ratios similar to coeval seawater, suggests that the dolomite probably formed initially in a marine environment during early diagenesis. The low $\delta^{18}O$ values of the dolomite, however, indicate considerable burial modification. Correlations between texture and geochemistry, as well as among various parameters (Sr, Fe $\delta^{18}O$, and $^{87}Sr/^{86}Sr$), demonstrate that dolomite samples with increased modification are characterized by coarser textures, lower Sr and higher Fe concentrations, and lower $\delta^{18}O$ values and $^{87}Sr/^{86}Sr$ ratios. These correlations, along with geochemical comparison with associated limestone, not only suggest that the dolomite was modified by fluids depleted in ^{18}O, but also indicate that the lower $^{87}Sr/^{86}Sr$ ratios of many (35%) dolomite samples relative to Early Ordovician seawater resulted from diagenetic modification. On this basis, we conclude that (1) modification of the dolomite by basin-derived brines can be ruled out; (2) modification by younger seawater, seawater-meteoric mixtures, and fluids derived from early compaction of younger shales is possible; but (3) the dolomite seems most likely to have undergone long-lasting modification by meteoric water which gained low $^{87}Sr/^{86}Sr$ ratios by infiltrating younger carbonates, probably during emergence of the carbonate platform coincident with regional Paleozoic unconformities.

Reprinted as published in *Journal of Sedimentary Petrology*, v. 61, p. 161, March 1991.

Thermal Conditions in the Anadarko Basin, Oklahoma

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Heat flow, bottom-hole temperature (BHT), and thermal conductivity data are used to evaluate the present thermal conditions in the Anadarko basin. Heat flow values decrease from 54–62 mWm^{-2} in the northern part of the basin to 39–53 mWm^{-2} in the southern portion of the basin. The variation in the regional conductive heat flow is controlled by basin geometry and by the distribution of radiogenic elements in the basement. The heat flow, thermal conductivity, and lithologic information were combined to construct a 3-D model of the temperature structure of the Anadarko basin. The highest temperatures in sedimentary rocks older than Pennsylvanian are offset 35 km north-northwest of the deepest part of the basin. This offset is related to the regional increase in heat flow to the north and to the presence of high thermal conductivity granite wash adjacent to the Wichita Mountains. A plot of the temperature difference between the equilibrium temperatures estimated from the model and the measured BHTs as a function of depth is remarkably similar to the published correction curve for BHTs for wells in Oklahoma.

Vitrinite reflectance and apatite fission-track (FT) data are used to estimate the paleogeothermal conditions in the basin. Published vitrinite reflectance values are

consistent with a past geographic temperature distribution comparable to the observed distribution with the maximum values offset from the basin axis. FT analysis of sandstones from wells in the southeastern portion of the basin indicates that subsurface temperatures were at least 30°C higher than at present, suggesting the possibility of substantial erosion in this area.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 75, p. 607, March 1991.

Sulfidization and Magnetization above Hydrocarbon Reservoirs

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Geochemical and rock magnetic studies of strata over Cement oil field (Anadarko basin, Oklahoma), Simpson oil field (North Slope basin, Alaska), and the Edwards deep gas trend, south Texas coastal plain, document changes in original magnetizations caused by postdepositional iron sulfide minerals that are, or may be, related to hydrocarbon seepage. At Cement, ferrimagnetic pyrrhotite (Fe_7S_8) formed with pyrite and marcasite in Permian red beds. The Fe–S minerals contain isotopically heavy, abiogenic sulfur derived from thermal degradation of petroleum and (or) isotopically light sulfur derived from sulfate-reducing bacteria fed by leaking hydrocarbons. At Simpson, ferrimagnetic greigite (Fe_3S_4) dominates magnetizations in Upper Cretaceous nonmarine beds that contain biodegraded oil. Sulfur isotopic data are consistent with, but do not prove, a genetic link between the greigite ($\delta^{34}S$>+20 per mil) and seepage. In middle Tertiary sandstones of southeast Texas, pyrite and marcasite formed when abiogenic H_2S migrated upward from deep reservoirs, or when H_2S was produced at shallow depths by bacteria that utilized organic material dissolved in migrating water from depth. The sulfide minerals replaced detrital magnetite to result in a systematic decrease in magnetic susceptibility toward faults that connect deep petroleum reservoirs to shallow sandstone. Our results show that abiologic and biologic mechanisms can generate magnetic sulfide minerals in some sulfidic zones of hydrocarbon seepage. The magnetizations in such zones are diminished most commonly by replacement of detrital magnetic minerals with nonmagnetic sulfide minerals or are unchanged if such detrital minerals were originally absent.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 75, p. 661, March 1991.

Regional Geologic Characteristics Relevant to Horizontal Drilling, Woodford Shale, Anadarko Basin, Oklahoma

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Horizontal drilling in the Late Devonian–Early Mississippian Bakken Formation of the Williston basin has spurred new interest in other black shales as primary hydrocarbon reservoirs. The Late Devonian–Early Mississippian Woodford Shale,

which is similar in some respects to the Bakken Formation, is a major source of oil and gas in the Anadarko basin of Oklahoma and could prove to be a significant reservoir rock as well. The three regional geologic characteristics of the Woodford discussed here are of likely importance to horizontal drilling programs, although direct relations to drilling strategy cannot be developed until empirical data from horizontal tests become available.

First, the Woodford Shale is composed of the three distinct depositional units (the upper, middle, and lower informal members) with different physical and geochemical properties. The middle member has higher kerogen content [average total organic carbon (TOC) = 5.5 wt.%] than the upper and lower members (average TOC = 2.7 and 3.2 wt.%, respectively).

Second, a paleotopographic high that was rising before and during Woodford deposition divided the Woodford Shale into northeast and southwest depocenters. This high is interpreted as a basin-margin forebulge that developed as the direct result of loading and subsidence along the central trough of the southern Oklahoma aulacogen.

Third, Woodford depositional patterns are overprinted by thermal-maturity trends shaped primarily by differential burial of the Woodford during Pennsylvanian and Permian time. The Woodford Shale northeast of the forebulge is generally immature to marginally mature, whereas its thermal maturity southwest of the forebulge ranges from mature to postmature with respect to oil generation. A formation resistivity of about 35 ohm-m approximates the updip limit of oil-saturated Woodford Shale from which free oil might be produced from fracture systems.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 75, p. 1128, June 1991.

Biothem-Based Mississippian Transect from the Basin and Range Province to the Anadarko Basin

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A west-to-east transect, constructed using the "Biostratigraphic Package Approach" of Lane and Frye and illustrating the biostratigraphic, lithologic, and depositional sequence relationships within the Mississippian system, extends from the basin and range province across the Transcontinental Arch (TA) and into the Anadarko basin. The transect is based on both published and proprietary biostratigraphic data. It was constructed primarily to portray the regional distribution and exploration significance of biothems relative to the axis of the TA. These biothems are biostratigraphic units that are wedge- or lens-shaped bodies of strata that are bounded by paleontologically recognizable unconformities in their updip extents, are conformable with underlying and overlying biothems in their maximum shelfal development, are conformable or bounded by surfaces of nondeposition and/or submarine erosion in their downdip, basinal extremities, and also contain a logical sequence of depositionally related facies.

An unexpected result of constructing the transect was the recognition of an apparent compensatory temporal and spatial distribution of Mississippian biothems. This distribution is interpreted to imply that biothems deposited during relative highstand events on one flank of the TA are time-equivalent to biothems deposited during relative lowstand events on the opposite flank of the TA. Plate-scale tilting, along with local subsidence and uplift, is suggested as the overriding mechanism controlling deposition along the extent of the transect. A further conclusion is that the lack of transgressive or regressive coincident Mississippian biothems on either flank of the TA questions the advisability of imposing the Mississippi Valley-derived eustasy curve on western flank depositional sequences.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 75, p. 577, March 1991.

Using Cathodoluminescence to Map Regionally Zoned Carbonate Cements Occurring in Diagenetic Aureoles above Oil Reservoirs, Velma Oil Field, Oklahoma

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Strongly reducing chemical conditions related to the microseepage of petroleum above oil reservoirs appear to cause mappable variations in the trace element content of resulting late-diagenetic carbonate cements. Published geochemical studies show that changes in Fe and Mn concentration in carbonate cements are a cause of chemical zonation in some diagenetic aureoles related to oil reservoirs. Fe and Mn are, respectively, the common quencher and activator of cathodoluminescence (CL) in carbonate minerals. Thus, CL can be used as a sensitive detector of changes in Fe/Mn ratio, if other trace element CL sensitizers/quenchers have a negligible effect in the samples. Our samples seem to respond to changes in Fe/Mn suggesting that in this case CL can be used to make a quick visual estimate of Fe/Mn content in the carbonate cements.

Application of the method to Velma oil field, Oklahoma, suggests that the cathodoluminescent properties form a regionally mappable zoned pattern seemingly related to the production field. The diagenetic aureole at Velma, Oklahoma, is particularly well developed. It consists of dark reddish-brown sandstone containing abundant iron sulfide and ferroan carbonate cements over the reservoir, surrounded by iron-poor country rock. The regional cathodoluminesence pattern observed in the carbonate cements roughly correlates with the observed changes in iron content with dull- or nonluminescent cement (high Fe/Mn) over the field and dull to bright luminescence (low Fe/Mn) on its flanks.

The regional Cl zonation is interpreted to be caused by vertical microseepage of petroleum producing reducing conditions over the reservoir. These strong reducing conditions produce Fe and Mn in the 2+ state allowing these elements to easily substitute for Ca^{2+} in the carbonate crystal lattice. CL in such high Fe/Mn carbonates will be dull- or nonluminescent. The less reducing conditions conjectured to exist off the reservoir produce Fe^{3+} but Mn remains in the 2+ state producing a low Fe/Mn carbonate cement that is highly luminescent.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 75, p. 538, March 1991.

Application of a Transpressive Tectonic Model to a Shallower Pool Development, Eola Field, Garvin County, Southern Oklahoma

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The Eola field was initially developed in the 1950s, producing from Ordovician Simpson sand at depths of 11,000 ft to 15,000 ft. Application of a new geologic model has aided the development of the fractured Mississippian Sycamore Limestone and the Devonian Hunton Limestone between 6000 ft and 8000 ft.

A detailed investigation of the field employing an interactive computer-based geologic interpretation system can document two phases of faulting. The most significant was a transpressive deformation, followed by west over east thin-skinned thrusting. The most prominent structure of the Eola field is an east-west-trending overturned syncline anticline pair with the Eola fault cutting through the crest of the anticline. There is 300–500 ft of apparent normal offset on this fault. The basal Oil Creek Formation is a 240-ft-thick oil sand north of the fault. South of the fault the equivalent section becomes a 200-ft-thick brown shale. The Hunton Formation is 250-ft thick north of the fault; south of the fault only the bottom 45 ft of the Hunton exists. These stratigraphic mismatches and the structural inconsistency of an apparently normal fault in a zone of extreme shortening are best explained by incorporating a lateral component of fault motion during compression. The lack of a stratigraphic match within the field implies at least 3–5 km of lateral motion.

Later, west over east thin-skinned thrusting offsets the Eola fault and the anticlinal axis. These late-stage shallow thrusts define the upper limits of producible Sycamore and Hunton reservoir.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 75, p. 608, March 1991.

Three-Dimensional Fluvial Architecture of the Gypsy Sandstone (Pennsylvanian), Central Oklahoma

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Exposures of the Virgilian-age Gypsy Sandstone west of Tulsa, Oklahoma, were used with shallow cores to determine the three-dimensional geometry of bounding surfaces and channel-fill complexes within a multistoried fluvial sand body.

Individual fourth- and fifth-order bonding surfaces were initially mapped on two parallel 300-m-long road cuts using photomosaics. Fifth-order surfaces bound three large and three smaller channel-fill complexes. Vertical sequences within the larger channel-fill complexes typically consist, from the base up, of a 0.3–1 m thick lag of trough cross-bedded, granule- to cobble-sized mudstone intraclasts that grade up into 0.1–1.5 m thick trough sets of medium- to fine-grained sublithic arenite. This part of the sequence is often carbonate cemented. Planar and ripple-laminated fine sandstones occur near the top of the sequence. Some sequences are capped by red,

root-mottled siltstone. Laterally, channel-fill complexes are either truncated by fifth-order bounding surfaces or thin into the adjacent red siltstone unit.

Twenty-two shallow cores, spaced 30–60 m apart, were cut 5 to 245 m from the northern road cut. Fifth-order bounding surfaces associated with the three large channel-fill complexes could be recognized and correlated between cores and the road cuts. Third- and fourth-order bounding surfaces, while recognizable on the outcrop facies and in individual cores, could not be traced throughout the study area. Individual channel-fill complexes are up to 10 m thick and 100–250 m wide. They have a high degree of longitudinal continuity.

Paleocurrent and other sedimentologic data suggest that, where they can be identified, macroforms, while lacking well-defined sigmoidal bedding, are lateral accretion deposits modified by chute channels.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 75, p. 564, March 1991.

The Physical Response of Dip-Measuring Logging Devices to Clastic Sedimentary Structures: A Case Study

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An understanding of the physical response of dip-measuring devices to sedimentary structures within sandstones can provide important constraints on reservoir character and geometry. To address this issue, BP Exploration cored a shallow well in the Gypsy Sandstone (Pennsylvanian) near Tulsa, Oklahoma. The core was fully analyzed to describe and orient the sedimentary structures within the sandstone. The hole was logged with four dip-measuring devices: the six-arm resistivity dipmeter, six-arm acoustic dipmeter, Circumferential Acoustic Scanning Tool (CAST), and Formation MicroScanner (FMS). Full-scale playbacks of the logs were prepared for correlation with the sedimentary features.

Detection of sedimentary features is a function of tool resolution, scale of the structure being sampled, and presence of contrasting physical properties associated with the structures. Large-scale (>4 in.) bedding structures were detected by both of the resistivity devices; small-scale (<4 in.) structures were detected only by the FMS because of its relatively dense radial sampling. The acoustic devices were effective for detecting large-scale interbedding. On a small scale, the acoustic six-arm dipmeter could only detect borehole-crossing features. The CAST detected small-scale interbedding and other structures but was unable to resolve features smaller than 3 in. due to limited impedance contrasts.

Current logging-tool technology and processing allow for identification and orientation of small-scale sedimentary features. The CAST and especially FMS are best suited for sedimentological studies due to their superior borehole coverage and resolution.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 75, p. 605, March 1991.

AAPG—The Formative Years (1915–1926)

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In the year 1915 there were no more than a few hundred geologists in the world who might identify themselves as petroleum specialists. Operators had had good success drilling along creeks in Pennsylvania, on hills in Oklahoma, and on mounds in the Gulf Coast without much regard for the subsurface geology. Although Union Oil of California had formed a geological department in 1900, geological input was generally looked upon with skepticism.

It is reported that when Bill Skelly hired the first geologist to work for his company, he went to great pains to inform his investors that he was paying the man out of his own pocket rather than from corporate funds. It's not hard to conjure up a conversation over drinks in the lounge of the Hotel Tulsa between Bill Skelly, Harry Sinclair, and Paul Getty in the course of which Skelly remarks that "All of the easy oil has been found! I think I'll hire a geologist."

By the fall of 1915, J. Elmer Thomas, a geologist with Minnehoma Oil Company in Tulsa and later to become the first president of AAPG, felt motivated to invite 30 fellow petroleum geologists to an October 2 dinner at the Hotel Tulsa for the purpose of, in his own words, "fostering friendship within our ranks and of permitting the mutual benefits that would arise from the occasional exchange of data and ideas . . ." Twenty-seven attended and during the discussion that took place, James H. Gardner suggested that they form a geological society, Professor Charles H. Taylor of the University of Oklahoma, who had discussed just such a possibility with Everett DeGolyer earlier that year, volunteered to host a meeting in Norman. Invitations were mailed October 25th and the convention was held on January 7–8, 1916. Approximately 60 geologists attended.

During the next ten years, membership grew from 94 to 1504. The name Southwestern Association of Petroleum Geologists was adopted in 1917 and changed to American Association of Petroleum Geologists in 1918. Association business was conducted from the offices and homes of the members of the Executive Committee until August, 1926, when a permanent office was established in Tulsa under business manager J. P. D. Hull.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 75, p. 563, March 1991.